SOME MATERIALS OF LOW THERMAL CONDUCTIVITY.

BY EZER GRIFFITHS, D.Sc., NATIONAL PHYSICAL LABORATORY.

Some Materials of Low Thermal Conductivity.—From the point of view of the refrigerating engineer, the ideal material for cold storage insulation would be an assemblage of minute gas cells totally enclosed in a light framework impervious to moisture. Hermetical sealing of the cells is essential, for a water logged material is useless for insulation purposes. Besides the fact that the value of the thermal conductivity of water is about ten times that of the conductivity of the materials usually employed for insulating purposes, the presence of moisture is liable to set up decomposition in substances of organic origin. Consequently many excellent thermal insulators, such as cotton waste and wood sawdust, are ruled out on account of their rapid deterioration in the presence of water.

Another important factor which has to be considered in assessing the value of an insulator, especially for marine work, is the weight per cubic foot of the material. A modern refrigerating ship of 6400 tons requires about 400 tons of cork.¹ So a saving of a few per cent. is well worth while.

A material of low weight per cubic foot has the additional advantage

¹ The following particulars concerning two ships of the Nelson Line were kindly supplied by Mr. A. R. T. Woods, M.I.Mech.E., M.I.N.A.

Ship built in 1911. Registered gross tonnage 7490 tons. Insulated throughout :—

Approx. Weights.

Hull, engines and boilers	4490 tons.
Refrig. machinery and brine piping, etc.	610 „
Insulation (silicate cotton) and timber	1050 „

Empty ship, total weight = 6150 tons.

Total capacity of cargo spaces = 328,980 cubic feet
„ „ „ „ „ = 3100 tons chilled meat.
„ „ „ „ „ = 3300 „ frozen meat.

Ship built in 1920. Registered gross tonnage 8442 tons. Insulated throughout :—

Approx. Weights.

Hull, engines and boilers	4624 tons.
Refrig. machinery and brine piping, etc.	686 „
Insulation, granulated cork	430 „
„ timber	660 „

Empty ship, total weight = 6400 tons.

Total capacity of cargo spaces = 414,570 cubic feet.
„ „ „ „ „ = 3940 tons chilled meat.
„ „ „ „ „ = 4150 „ frozen meat.

Silicate cotton packs	22 lbs. per cubic foot.
Cork (granulated) „	7 „ „ „ „

SOME MATERIALS OF LOW THERMAL CONDUCTIVITY 253

that the heat which has to be abstracted in cooling down the stores is less, and this leads to economy of working.

The heat insulators in common use at the present day are slab cork, granulated cork, slag wool, and charcoal. These are so well known as not to need further description¹ and the purpose of the present communication is to bring to the attention of refrigerating engineers a few materials which may be worthy of study under practical cold storage conditions, for they possess at least one essential characteristic of a cold stores insulator, namely, low thermal conductivity.

Expanded Rubber.—Methods have been devised for the conversion of rubber into a highly cellular form, the resulting product having an exceedingly low density.

When viewed under a low power microscope, the material shows a structure apparently made up of minute cells bounded by rubber membranes. The cellular structure of the material immediately suggests the possibility of its use as a heat insulator.

The small samples we obtained differed considerably as regards density and presumably this variable can be controlled by the method of manufacture as well as its physical state, whether soft or hard. Samples of the soft variety varied in density from 0.059 to 0.12 C.G.S. units (3.7 to 7.5 lbs. per cubic foot), while a hard variety resembling ebonite had a density of 0.17 (10.6 lbs. per cubic foot).²

It would be a matter of considerable theoretical interest to ascertain the relation between the density of the sample and its thermal conductivity, but sufficient material has not been available for such tests. The conductivity of some of the material in sheet form has been determined and varied from about 0.00009 to 0.00012 C.G.S. units, the actual value being dependent, apparently, upon the precise method of manufacture, etc.

Now the weight per cubic foot of the samples tested was only about 5 to 7 lbs., whereas slab cork weighs 11 to 13 lbs. so that when comparisons are made on the basis of the weight of equivalent amounts of insulation the rubber shows a marked saving.

Tests of the insulating value of expanded rubber clippings when packed into an interspace have also been carried out. The clippings had been prepared from a sheet and measured roughly $\frac{1}{2}$ inch $\times$ $\frac{1}{4}$ inch $\times$ $\frac{1}{4}$ inch blocks with considerable variations from the mean. A density determination on some of the fragments gave the value 0.09 ± 0.02 , i.e. 5.62 ± 1.25 lbs. per cubic foot.

In the test the material was evenly packed on either side of a hot plate measuring 8 inches by 8 inches surrounded by a 2 inch guard ring. The thickness of each layer was $1\frac{1}{8}$ inches.

In the first test the packing was light, the material being pressed down slightly. The weight of material per cubic foot under these conditions was 2.6 lbs.

The data obtained are given in Table I. below.

The material was then taken out of the apparatus and repacked uniformly, but pressing in as much as possible. The weight of material per

¹ Data as to the thermal conductivity of these materials will be found in Special Report No. 5 of the Food Investigation Board entitled *Report on Heat Insulators*, published by H.M. Stationery Office.

² The density of ordinary red rubber vulcanised is variable. Two samples gave 1.31 and 1.77, i.e. 82 and 110 lbs. per cubic foot respectively.

254 SOME MATERIALS OF LOW THERMAL CONDUCTIVITY

cubic foot under these conditions was 4 lbs. The closer packing has increased the insulating efficiency by 12 per cent. (See Table I.)

So it would appear that in a granulated form the same insulating efficiency can be obtained with approximately half the weight of this material, as compared with granulated cork and about one-quarter the weight when compared with slab cork.

A somewhat parallel case to this, as regards the difference in weight per cubic foot, granulated and in sheets, is given by cork. In the baked slab form cork weighs about twice as much as the granulated and gives roughly the same insulating efficiency.

Since it is possible to control, in the course of manufacture, the density of the expanded rubber it would be of interest to ascertain the limit to which the reduction in density can be carried.

TABLE I.
CLIPPINGS OF EXPANDED RUBBER.
Density of Packing, 2.6 lbs. per cubic foot.

Date.	Time.	Cold Face Temperatures.		Hot Face Temperatures.		Mean Temp. of the Material.		Conductivities.	
		° Cent.	° Fahr.	° Cent.	° Fahr.	° Cent.	° Fahr.	C.G.S. Units.	B.T.U.'s per sq. ft. per Hour for 1" Thickness and for 1° F. diff. in Temp.
Aug. 7th	11 A.M.	20	68	50	122	35	95	0.000122	0.343
„ 8th	9 A.M.	20	68	50	122	35	95	0.000117	0.340
„ 9th	12 A.M.	20	68	50	122	35	95	0.000118	0.342
Probable value								0.000118	0.342

Density of Packing, 4.0 lbs. per cubic foot.

Aug. 13th	11 A.M.	20	68	50	122	35	95	0.000105	0.305
„ 14th	9 A.M.	20	68	50	122	35	95	0.000107	0.311
„ 15th	10 A.M.	20	68	50	122	35	95	0.000105	0.305
Probable value								0.000106	0.308

The material differs markedly from ordinary vulcanised red rubber in its properties, a notable characteristic being its softness. The questions of the durability of the material under rough usage and its chemical stability are ones which merit careful investigation.

Rubber is permeable to water vapour and to many gases, so the gas cells cannot be regarded as hermetically sealed. A sample of the material tested under water for a period of 300 hours showed a progressive increase of weight with time. It cannot yet be stated whether this water absorption is due to water vapour permeating the rubber and forming an adsorbed film on the surface of the cells, or whether it is due to capillary absorption similar to the effect obtained with charcoal. The fact that the action is slow would appear to indicate that it is due to water vapour permeating through the rubber, but it must be remembered that in the case of capillary attraction the action would be slow if the capillaries were close-ended and the water had to dissolve the gas as it flowed along the capillary.

SOME MATERIALS OF LOW THERMAL CONDUCTIVITY 255

The constitution of the material does not appear to be simply one of gas enclosed in cavities with solid rubber walls, and it is probable that an appreciable amount of gas is absorbed in the rubber. The determination of the state in which the gas is present in the material is a perplexing chemical problem.

In the present stage of our knowledge concerning this new material, it is difficult to express an opinion as to its value as a practical heat insulator for lining the walls of a store. A long period test on a reasonably large scale is really essential, and the quantity of material necessary for such a test has not yet become available.

Balsa Wood.—Balsa is the wood of a large tropical tree growing in Ecuador. It is probably the lightest wood known. The samples we have tested have varied in weight from 5·7 to 8·6 lbs. per cubic foot.¹

As a structural material it is decidedly weak and liable to damage by blows, etc., but it has the advantage over materials such as cork that it can be worked with ordinary wood-working tools which, however, must be very sharp and run at high speed.

In the natural state the wood is subject to decay, but it is claimed that with preservatives it is possible to make the wood sufficiently waterproof to enable it to be used for cold storage insulation.

When the material is to be employed in dry situations it can be surfaced with a veneer of hard wood.

The results of tests on several varieties of the material are given in Table II. below :—

TABLE II.

BALSA WOOD.

Specimen of 2" Board weighing 5·75 lbs. per cubic foot.

Date.	Time.	Cold Face Temperatures.		Hot Face Temperatures.		Mean Temp. of the Insulating Material.		Conductivities.	
		° Cent.	° Fahr.	° C. nt.	° Fahr.	° Cent.	° Fahr.	C.G.S. Units.	B.T.U.'s per Hour per sq. ft. for 1" Thickness and for 1° F. diff. in Temp.
March 4th	8 P.M.	11	52	75	167	43	109	0·000112	0·326
„ 5th	2 P.M.	10	51	76	168	43	109	0·000114	0·332
Probable value								0·000113	0·329

Specimen of 2" Treated Board weighing 8·6 lbs. per cubic foot.

July 28th	5	26	79	60	140	43	109	0·000121	0·351
„ 29th	11 A.M.	26	79	60	140	43	109	0·000133	0·386
„ 31st	10 A.M.	26	79	60	140	43	109	0·000129	0·374
Probable value								0·000130	0·377

Fibres of Kingia Australis.—The possibility of using this material

This may be compared with mahogany, which weighs about 45 lbs. per cubic foot.

256 SOME MATERIALS OF LOW THERMAL CONDUCTIVITY

was suggested by Mr. R. A. Fowler, Forest Produce Laboratory, Perth, Australia, who supplied the following information concerning it.

It is a fibrous waste from a tree known as "Kingia Australis." This plant is peculiar to Western Australia where it grows on the poorer soils of the coastal belt. The tree consists of a long cylindrical stem up to about 20 feet high and a foot in diameter, surmounted by a tuft of long grass-like leaves. The stems are usually black in outward appearance, owing to charring by forest fires, and are composed of an outer sheath of persistent leaf bases packed very closely together, an inner sheath an inch to 2 inches in thickness of longitudinal fibres cemented together in a close matrix, and an inner core of closely packed short fibres. The inner sheath of long fibres is the only portion of the plant at present used.

A waste product is obtained in cleaning the fibres from the cementing matrix in the form of dust and fibrous material.

The results of a series of tests on this material are given in Table III. below:—

TABLE III.
FIBRES OF WOOD, KINGIA AUSTRALIS.

Density of Packing, 8.4 lbs. per cubic foot.

Date.	Time.	Cold Face Temperatures.		Hot Face Temperatures.		Mean Temp. of the Material.		Conductivities.	
		° Cent.	° Fahr.	° Cent.	° Fahr.	° Cent.	° Fahr.	C. G. S. Units.	B. T. U.'s per sq. ft. per Hour for 1" Thickness and for 1° F. diff. in Temp.
Aug. 27th	9 A.M.	16	61	32	90	24	75	0.000118	0.342
" 28th	10 A.M.	16	61	32	90	24	75	0.000117	0.339
" 29th	11 A.M.	16	61	32	90	24	75	0.000115	0.334
" 30th	11 A.M.	16	61	32	90	24	75	0.000117	0.339
" 31st	11 A.M.	16	61	32	90	24	75	0.000117	0.339
Probable value								0.000117	0.339

Eel Grass Mats.—This material is made up of cured eel-grass sewn in between sheets of strong paper. The grass grows in salt water and contains silicon to a large extent. It does not harbour insects or vermin, which is a most valuable characteristic.

The value of eel grass as a thermal insulator appears to have been realised at an early date in the United States, for it is stated that a dwelling house built in 1635 in Dorchester, Mass., was lined with the grass stuffed between the studding, and the material appears to have been in a good state of preservation after a lapse of more than two and a half centuries.

A sample of commercial matting was obtained and tested in two states of packing. The results are given in Table IV.

Whether the material will meet the stringent requirements of the refrigerating engineer is a matter for experiment under service conditions.

SOME MATERIALS OF LOW THERMAL CONDUCTIVITY 257

TABLE IV.
EEL GRASS MATS.*Density of Packing, 9.4 lbs. per cubic foot.*

Date.	Time.	Cold Face Temperatures.		Hot Face Temperatures.		Mean Temp. of the Material.		Conductivities.	
		° Cent.	° Fahr.	° Cent.	° Fahr.	° Cent.	° Fahr.	G.G.S. Units.	B.T.U.'s per sq. ft. per Hour for 1" Thickness and for 1° F. diff. in Temp.
May 8th	10 A.M.	15	59	45	113	30	86	0.000109	0.318
„ 9th	9 A.M.	15	59	45	113	30	86	0.000108	0.314
Probable value								0.000108 ₅	0.316

Density of Packing, 13.4 lbs. per cubic foot.

May 16th	11 A.M.	19	66	41	106	30	86	0.000117	0.341
„ 17th	11 A.M.	19	66	41	106	30	86	0.000117	0.341
Probable value								0.000117	0.341

Compressed Peat.—Peat, variously treated, is being extensively used on the Continent for heat insulation. The chief merit of the material is its cheapness. For cold storage work the peat is impregnated with a bituminous substance to protect it from the effect of damp. Data concerning tests on “treated” and “untreated” material are given in Table V. below.

The heavy weight per cubic foot of the material—20 to 30 lbs.—is a disadvantage.

TABLE V.
COMPRESSED PEAT.*Weight of Specimen, 20 lbs. per cubic foot.*

Date.	Time.	Cold Face Temperatures.		Hot Face Temperatures.		Mean Temp. of the Material.		Conductivities.	
		° Cent.	° Fahr.	° Cent.	° Fahr.	° Cent.	° Fahr.	C.G.S. Units.	B.T.U.'s per sq. ft. per Hour for 1" Thickness and for 1° F. diff. in Temp.
Aug. 7th	10 A.M.	23	73	51	124	37	99	0.000175	0.509
„ 8th	10 A.M.	23	73	51	124	37	99	0.000176	0.512
Probable value								0.000176	0.512

PEAT TREATED WITH BITUMINOUS MATERIAL.

Weight of Specimen, 29.5 lbs. per cubic foot.

Aug. 19th	11 A.M.	24	75	52	126	38	100	0.000175	0.507
„ 20th	11 A.M.	24	75	52	126	38	100	0.000173	0.501
„ 21st	10 A.M.	24	75	52	126	38	100	0.000173	0.502
Probable value								0.000173	0.502

A sample obtained from another source gave the value 0.000167 C.G.S. units for the thermal conductivity at 38° C.

258 SOME MATERIALS OF LOW THERMAL CONDUCTIVITY

In conclusion it may be pointed out that the thermal conductivity of insulating materials in general is not an invariable physical constant. So it follows that it is advisable to test samples of various consignments just as it is desirable to determine the calorific value of a fuel.

The experiments recorded in this paper and the other on Thermometric Lag constitute a part of the programme of work for the Engineering Committee of the Food Investigation Board.

We desire to record our thanks to the Engineering Committee and to our director for their interest and encouragement.